Buried Ordnance Locator

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LONG-TERM GOALS

Explosive ordnance disposal (EOD) technicians require the capability for standoff detection and classification of buried anomalies. Current fielded man-portable sensors provide little to no standoff detection and no classification of detected anomalies. The development and demonstration of techniques for standoff detection and classification of buried metallic and non-metallic unexploded ordnance (UXO) will result in a prototype man-portable multi-element electromagnetic vector sensor array system.

OBJECTIVES

The objectives of this program are to: (1) collect Experimental Time Domain Electromagnetic (TDEM) data to determine baseline electromagnetic (EM) signatures of targets with simple geometrical shapes, (2) use the experimental data to validate results and theoretical knowledge to develop computer algorithms for forward and inverse modeling of the responses of TDEM systems to UXO targets (These algorithms will be the basis for characterization of buried anomalies), and (3) assess the capability of a multi-element magnetic field sensor array to detect buried UXO-like items and classify detected items as UXO or non-UXO shaped. More specifically, demonstrate that a Spin-dependent Tunneling Device (STD) or High Temperature Superconducting Quantum Interference (HT SQUID) multi-element gradient sensor can determine the location of a UXO item at an appropriate range relative to target size and magnetic signature (e.g., a 150 mm projectile at a range of four meters) with an EM source and provide information for shape assessment.

APPROACH

This program was started with two prime contractors. Geometrics pursued HT SQUID technology in an effort to develop a sensitive passive gradiometer. Blackhawk started developing the necessary components for a TDEM active locator for detection and characterization of UXO. Since that time, Geometrics bought Blackhawk, resulting in a new company named Blackhawk Geometrics. The current approach has the following primary components: the development of an EM sensor, a tensor array, algorithms to enable classification, and a test bed for field characterization.

STD Sensor Development. Efforts sponsored by ONR were leveraged to assist in the development of Magnetoresistive SDT sensors suitable for the EOD application. The intent of the sensor development is to investigate new fabrication processes to improve the bandwidth and sensitivity beyond state-of-the-art SDT devices. In order to obtain improvements in sensitivity, thicker coils for feedback and biasing currents are needed. Low temperature deposition and insulation processes were developed to ensure the underlying SDT material is not damaged.

Tensor Arrays. The design philosophy for the SDT sensor is to create a cube using 54 SDT sensors. Each face of the cube has nine SDT sensors in a 3 x 3 matrix. Each pair of SDT sensors on opposite sides of the cube acts as a gradiometer. The term for this arrangement is a MagnetoCube array.

An 8-element HT SQUID tensor array was also designed and fabricated. This included development of all the associated electronics and the liquid nitrogen dewar system. The basic design is patterned after the Tristan model G377 3-axis geophysical magnetometer. Field tests were conducted to determine noise, frequency response and dynamic range and to determine other parameters, such as noise vibration and field worthiness.

Originally, the sensor selected for the final buried ordnance locator design could have been either of the sensors listed above. Neither sensor was pre-selected for the final design. However, with transmitter pulse size limits and cryogenic requirements of the SQUID, it was felt that it would be most useful to focus on the MagnetoCube instead of continuing with SQUID testing. It is possible that future advances in low power compact Micro Miniature Refrigerators would eliminate the need for liquid nitrogen and possibly even for liquid helium. If that were the case, it would be possible to build a compact low temperature SQUID tensor system. This would be the optimum tensor system since it would be possible to use intrinsic gradiometers with low temperature SQUIDs and would be the most sensitive tensor possible with current magnetic sensor technology. For now, the STD technology is a lower risk option that meets the current need.

Algorithm Development and UXO TDEM Response Characterization. Data will be collected to create a library of experimental TDEM measurements. A test bed containing suspended and buried inert UXO and canonical objects simulating typical UXO will be used. During development of the hardware, Blackhawk Geometrics will also develop software to operate the sensor array. Algorithm development includes forward and inverse modeling, sensor optimization, model-based discrimination, and databased discrimination. Software for the reduction of noise will also be developed.

Test Bed. A portable EM source will be designed, developed and tested for use with the combined sensor array. The final sensor design will be selected for the test bed. All system components will be integrated into a buried ordnance locator prototype. The prototype will be field tested and all data collected will be analyzed.

WORK COMPLETED

SDT Sensor Development. With the basic sensor design completed in FY99, the FY00 efforts focused on improving SDT sensor performance.

Tensor Arrays. The MagnetoCube was fully populated with STD sensors and tested on a laboratory bench. The HT SQUID tensor array was fabricated and tested in laboratory and field environments.

Algorithm Development and UXO TDEM Response Characterization. Additional work was done on the Mean Field Theory to model the EM scattering signature of spheroidal shapes. Numerical modeling was performed to verify the Mean Field Theory code.

Test Bed. A graphical user interface was developed for the Mean Field Theory code.

RESULTS

SDT Sensor Development. The initial STD sensors exhibited lower sensitivity than expected and significant 1/f noise. Improvements in SDT materials through modifications of the wafer processing techniques have increased the sensitivity of individual SDT sensors by two orders of magnitude and decreased the sensor noise significantly.

Tensor Arrays. The MagnetoCube was populated with the best sensors available at the time of fabrication. Since that time, the improved sensors became available. The MagnetoCube will be re-populated with the improved sensors before further testing is conducted. Figure 1 shows the MagnetoCube. During laboratory testing, an excitation coil was used to deliver a pulsed magnetic field in the vicinity of a solid aluminum sphere. The sensor cube measured the magnetic field versus time after the falling edge of the field pulse to determine the response from the sphere. A current pulse of 1.1A amplitude and 10ms duration was used through the coil to generate the field pulse. Figure 2 shows a diagram of the measurement setup. The coil is rectangular with a dimension of 31.1 cm along the x-axis and 26.0 cm along the y-axis. This preliminary testing was very valuable. Minor issues were resolved (e.g., sensor saturation by the transmit pulse) and data was collected. Figure 3 shows typical data for two sensors (paired for gradient measurement) on the MagnetoCube.

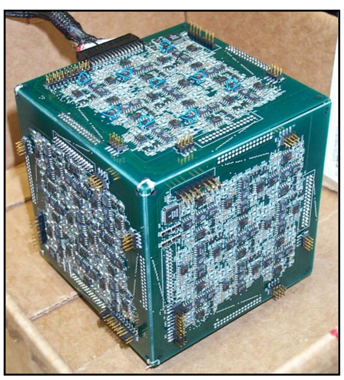

Figure 1. The MagnetoCube

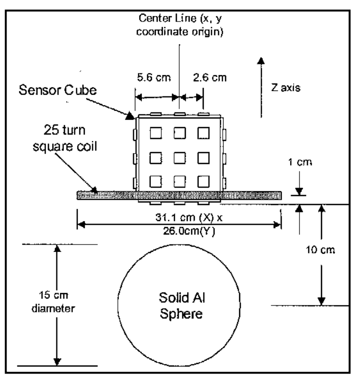

Figure 2. Experimental Setup for Initial Testing

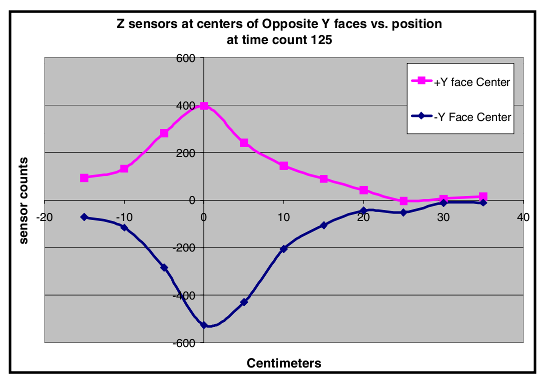

Figure 3. Typical Data from Two Sensors on the MagnetoCube.

The HT SQUID system was also subjected to initial testing. It was determined that the HT SQUID tensor array system can potentially be used for in the field UXO detection. Current HTS SQUID white noise is better than 30 fT/√ Hz (15 micro phio/√Hz), 1/f noise starts at several Hz. The system limitations are coming from the electronics slew rate limitations (50,000 phio/sec for present system, and has been shown elsewhere up to 1,000,000 phio/sec) and from intrinsic SQUID dynamic range limitations (about 50,000 phio or 0.5-1 Gs for present system, can be up to 8 G).

Algorithm Development and UXO TDEM Response Characterization. The mean field approach was successfully implemented to create a database of time domain electromagnetic scattering signatures.

The database consists of spheroidal, conducting but nonpermeable, scatterers with aspect (length to diameters) ratios ranging from 0.01 to 100. Aspect ratios greater than unity correspond to prolate spheroids, and are good models for cylindrical UXO. Aspect ratios less than unity correspond to oblate spheroids, and at the extreme end may be used to model flat circular plates which may serve as an approximate representation of clutter such as rocket tail fins.

The computed database will be compared to experimental data collected on spheroidal targets. This will require completing the development of the software for computing the external field generated by a given excitation coil, and computing the resulting voltage or magnetic field induced in the SDT sensor array. The required code is much simpler and runs much faster than the mode computation code, since it only performs integrals over the previously computed mode shapes.

To verify the Mean-Field Theory code, numerical modeling was undertaken. While unsuitable for real-time applications, numerical methods are useful for calibrating simpler analytic models and for investigating complex structures. As part of this investigation, we are utilizing a numerical package toward both of these ends. First, we calculated decay curves for solid ellipsoids for comparison to and calibration of the semianalytic mean-field theory. Second, we are using this numerical package for calculation of the response of asymmetrical, hollow shapes more closely resembling UXO, in order to assess the effects of our simple (ellipsoid) shape assumptions.

We completed setup of the finite-element engineering design-and-testing software ANSYS to model the time-domain EM response of axisymmetric targets, i.e., UXO. A series of macros has been written that appear on a custom toolbar. The user must supply a meshed longitudinal half-section of the projectile to be modeled. The target can contain both ferrous and nonferrous metals. The first macro program extrudes the 2D shape to a 3D object and prompts the user to input the position and orientation of the target with respect to the transmitter coil. A subsequent macro accepts input for transmitter and receiver parameters, including the transmitter waveform and the receive-time interval. The time decay of voltage in each receiver coil can be plotted, or any of the field parameters (potential, magnetic field, current density, and dissipation) can be visualized on the target at any time step. The time evolution of these quantities can also be viewed as animation.

We carried out tests of these procedures using a simplified, "canonical" projectile consisting of a cylindrical, hollow (dielectric) afterbody and a pointed, solid-metal forebody. The transmitter and receiver parameters were chosen to approximate the Geonics EM-61, although we examined the time decay over the whole pulse and not just in a single gate as the instrument actually records. Results show a distribution of currents in agreement with qualitative expectations; future quantitative studies will explore the role of projectile shape and composition on pulsed EM-induction signals.

Finite-element calculations are most effectively employed to heterogeneous, asymmetric, problems. We are preparing to make a series of calculations for more realistic ordnance that allows for both of these properties. At present we confine our attention to axisymmetric objects, which is still a good approximation to most bomb and projectile UXO (except for tail fins which are often detached anyway). In this way, we can rapidly define an object through simple digitization of its half cross-section and then use ANSYS to assign material properties and generate a 2-D mesh. A series of "macro" programs that facilitate the 3-D calculations was developed. The input 2-D mesh of the target is transformed into 3-D through axisymmetric extrusion. All of the parameters for the material, position, and orientation properties of the target, sensor, and background are interactively input and a

3-D mesh is constructed. Note that these same macros can be used for arbitrary 3-D targets if we construct these meshes offline from the macros.

Test Bed. A Graphical User Interface (GUI) has been written using Java for the Mean-Field Theory code to help the "casual" user. The graphical user interface (GUI) for the semianalytic mean-field theory has been nearly completed. This Java-language program accepts user input for target size, shape, position, and orientation and computes the time-domain EM response over a surface grid. The GUI is configured to function as both a stand-alone application and as an Internet web applet. The application has been tested and is undergoing final cosmetic changes. Both versions presently use a semiempirical EM model for testing and validation, pending completion of the mean-field theory.

IMPACT/APPLICATIONS

An EM-based man-portable tool with the capability to detect and classify ordnance targets will enable EOD technicians to better define hazards in the field. Once the hazards are known, the proper tools and procedures can be identified and used to dispose of the hazard safely.

TRANSITIONS

Current advanced development system requirements already exist that are awaiting appropriate technological developments before proceeding. The result of the Analysis of Alternatives (AOA) for an Advanced Ordnance Locator (AOL) performed in FY96 was to wait for characterization technology to mature before proceeding with an acquisition program. There is an AOA scheduled for FY01 to develop an AOL. Developments in sensor technology from this 6.2 effort will feed directly into the development of the AOL. PMS EOD has allotted funding in the Program Objective Memorandum for FY01 and beyond.

RELATED PROJECTS

DOE is conducting an effort to develop a superconducting magnetometer/gradiometer for advanced geophysical imaging. This effort is using SQUIDs to obtain EM measurements in boreholes. Some of the DOE work is directly applicable to our Standoff Detection effort. In fact, SQUID equipment used for the initial field tests was based on the DOE effort.

REFERENCES

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